SUPEROXIDE DISMUTASE MIMICS FOR THE TREATMENT OF OCULAR DISORDERS AND DISEASES

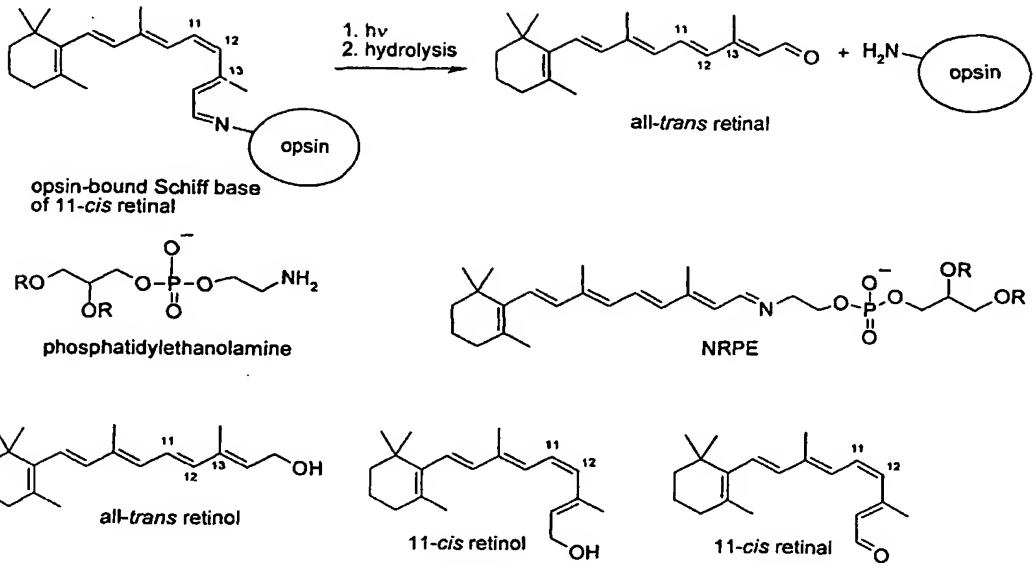
This application claims priority from U.S.S.N. 60/431,401, filed December 6, 2002.

The present invention relates to mimics of the enzyme superoxide dismutase for the treatment of the exudative and non-exudative forms of age-related macular degeneration, diabetic retinopathy, and retinal edema.

Background Of The Invention

Age-related macular degeneration (AMD) is the most common cause of vision impairment in the elderly population in western countries. The exudative or "wet" form of AMD is characterized by excessive neovascularization of the choroid, leading to retinal detachment and vision loss. The non-exudative or "dry" form is characterized by the accumulation of cellular debris called drusen in Bruch's membrane below the retinal pigmented epithelium (RPE). Exudative AMD, which occurs in a minority of patients with AMD, but is the more aggressive form of the disease, can be treated with limited success by laser photocoagulation therapy or photodynamic therapy. The latter procedure involves dosing of the affected area with a compound which, when irradiated with the appropriate wavelength of light, generates a reactive intermediate that destroys surrounding blood vessels. Currently there is no accepted therapy for the treatment of non-exudative AMD.

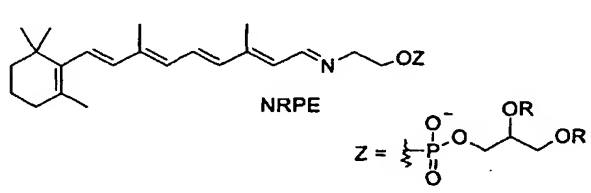
The visual cycle begins in photoreceptor cells with the absorption of a photon by an opsin-bound Schiff base of 11-*cis* retinal, which isomerizes to the corresponding all-*trans* retinal derivative. Release of the all-*trans* retinal from opsin is followed by condensation with phosphatidylethanolamine to form the new Schiff base NRPE (for N-Retinyl Phosphatidyl Ethanolamine). The NRPE so formed is transported across the photoreceptor cell outer membrane, where it is hydrolyzed to all-*trans* retinal. Enzymatic reduction to all-*trans* retinol is followed by transport into the RPE cell, where the compound is enzymatically isomerized to 11-*cis* retinol and oxidized to 11-*cis* retinal. This compound is transported back to the photoreceptor cell, where it forms an opsin-bound Schiff base to complete the cycle.



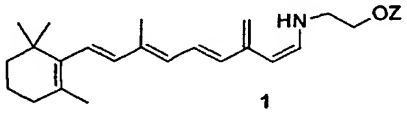
Besides helping to complete the visual cycle by recycling retinal, an important function of RPE cells is to support the continuous remodeling of retinal photoreceptors by phagocytosing their discarded outer segments and digesting them in RPE cell lysosomes. With age occurs the accumulation of a non-digestible pigment called lipofuscin in the lysosomes (the appearance of drusen is thought to correspond to lipofuscin accumulation). Lipofuscin absorbs light in the blue part of the spectrum and fluoresces in the yellow part of the spectrum. This fluorescence transfers energy to nearby oxygen, which becomes transformed into reactive oxygen species (ROS), such as superoxide ion. These ROS oxidize lysosomal membrane phospholipids, destroying membrane integrity. With membrane integrity breached the toxic contents of the lysosome leach into the cytosol, leading to RPE cell death. Without their supporting RPE cells retinal photoreceptors cannot participate in the visual transduction system, thus leading to blindness (for a review, see Winkler, et. al., Mol. Vision, Vol. 5:32, 1999, online journal; http://www.molvis.org/molvis/v5/p32; CA 132:235390).

Nakanishi and co-workers have elucidated the structure of and chemically synthesized the major fluorescent constituent of lipofuscin, called A2E (Nakanishi et. al., Proc. Natl. Acad. Sci. USA, Vol. 95:14609-14613, 1998, and references therein). This compound is thought to result biosynthetically from isomerization of electrophilic NRPE to the nucleophilic

enamine **1**, followed by condensation with another molecule of all-*trans* retinal to form azatriene **2**, electrocyclic ring closure to dihydropyridine **3**, autoxidation to the N-(2-hydroxyethyl)pyridinium species A2PE, and enzyamtic hydrolysis of the phosphate ester by the enzyme phospholipase D to afford A2E. The chemical structure of A2E-a molecule with two large hydrophobic "tails" and a charged polar "head"-suggests a detergent-like propensity to breach cell membranes. Along with its photooxidative capabilities, this may form an important component of the compound's toxic effects on RPE cells (for a review, see: Nakanishi et. al., Bioorganic and Medicinal Chemistry Letters, Vol. 11:1533-1540, 2001).



NRPE



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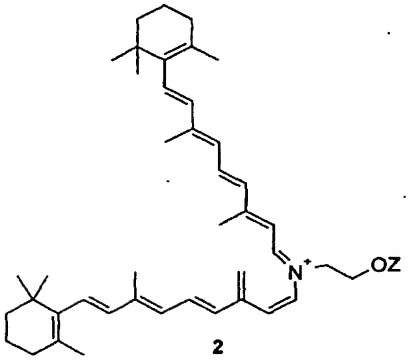

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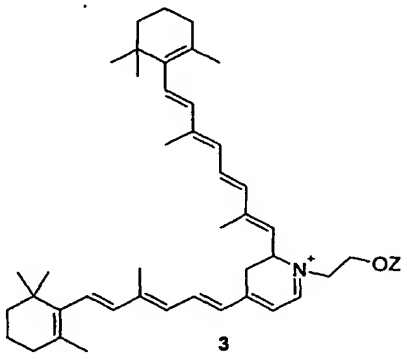

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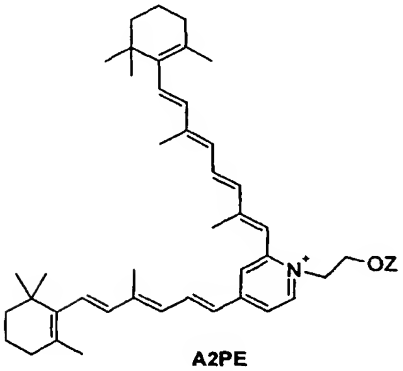
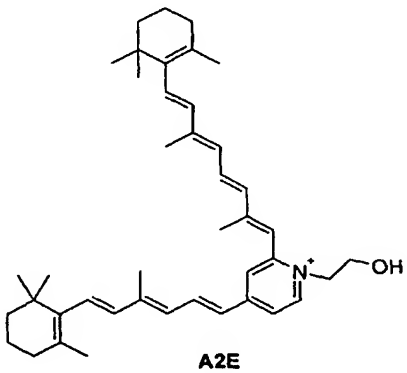


A2PE



A2E

The key role of defective transport of all-*trans* retinal out of the photoreceptor cell in the AMD disease process has been highlighted by the discovery that a genetic mutation that when homozygously present leads to a rare rapid macular degeneration called Stargardt's Disease may be associated, when heterozygously expressed, with non-exudative AMD (Dean et. al., Science, Vol. 277:1805-1807, 1997). The gene is called the ABCR gene (for ATP Binding Cassette Transporter Retina), whose protein product (also called rim protein) utilizes the energy released upon ATP hydrolysis to transport molecules across cell membranes. It is thought that the transporter's substrate is the Schiff base NRPE mentioned above. Absent sufficient functional transporter protein, the substrate NRPE accumulates in the photoreceptor cell instead of being shuttled out for reduction to retinol. Condensation with a molecule of all *trans*-retinal liberated from opsin and further reaction as mentioned above produces A2E. The A2E is ingested by RPE cells with the rest of the photoreceptor cell outer segment, where it accumulates in the lysosome. Supporting this hypothesis is the disclosure by Travis *et. al.* that A2E accumulation in RPE cells occurs much more rapidly in mice that are homozygously mutant in the ABCR gene, as compared to normal controls (Travis et. al., Proc. Natl. Acad. Sci. USA, Vol. 97:7154-7159, 2000).

Several studies have concluded that exposure of lipofuscin to light and oxygen under conditions mimicking those present in the retina leads to cell membrane peroxidation and cell death. Wihlmark et. al. disclosed that blue light irradiation of RPE cells with lipofuscin-loaded lysosomes increased cell membrane peroxidation and decreased cell viability, as compared to controls irradiated in the absence of lipofuscin (Wihlmark et. al., Free Radical Biol. Med. Vol. 22:1229-1234, 1997). Boulton and Shamsi have disclosed that dosing of cultured RPE cells with lipofuscin and exposing them to light decreased cell viability by over 40% after 24 hours and decreased lysosomal enzymatic and antioxidant activity, including that of superoxide dismutase (SOD) (Boulton and Shamsi, Invest. Ophthalmol. Vis. Sci., Vol. 42:3041-3046, 2001).

From this and other evidence, it is clear that certain defects in the body's natural defense mechanisms for dealing with toxic by-products of oxidative metabolism may play an important role in the development of AMD. One important component of this defense system is the SOD enzyme family.

These enzymes contain a low valent metal (either Mn^{II} or a Cu^{I}/Zn^{I} binuclear linkage) which catalyze the disproportionation of the highly reactive superoxide radical anion to the less toxic entities O_2 and H_2O_2. If not quenched the superoxide anion can (*via* its protonated form) abstract hydrogens from the allylic sites of fatty acids, leading to membrane damage. Additionally superoxide anion can react with NO to produce peroxynitrite, a potent oxidizing agent that is believed to be an important player in the untoward biological effects of excessive NO production.

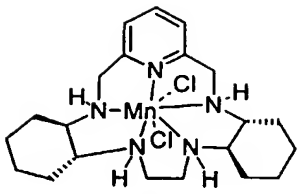
$$2\,H^+ + 2\cdot O_2^- \xrightarrow{SOD} H_2O_2 + O_2 \qquad \cdot O_2^- + NO^{\cdot} \longrightarrow \underset{\text{peroxynitrite}}{ONOO^-}$$

The potential importance of SOD in enhancing RPE cell viability is suggested by the disclosure of Boulton et. al, who. have reported that the damaging effects caused by irradiation of lipid membranes, proteins, and enzymes in the presence of lipofuscin can be significantly reduced by the addition of SOD (Boulton et. al., J Biol. Chem., Vol. 274:23828-23832, 1999). Even with respect to exudative AMD, a recent study in Japanese subjects disclosed a significant correlation between this form of the disease and a mutation in the SOD gene, corresponding to a valine/alanine substitution in the targeting sequence of the enzyme (Isashiki et. al., Am. J. Ophthalmol., Vol. 130:769-773, 2000). Thus, enhancing SOD function may be a viable target for preventing the development of both the exudative and non-exudative forms of AMD.

Oxidative stress also contributes to diabetes induced vascular and neural dysfunction. All forms of diabetes result in the development of diabetes specific microvascular pathology of the retina, renal glomerulus and peripheral nerve (M. Brownlee, "Biochemistry and Molecular Cell Biology of Diabetic Complications", Nature, Vol. 414:813-820, 2001). A prime source of the oxidative insult associated with diabetes is elevated levels of superoxide. Release of superoxide was detected in human blood vessels isolated from, patients with diabetes (Guzik, et al., "Mechanisms of Increased Vascular Superoxide Production in Human Diabetes Mellitus" Circulation, Vol. 105:1656-62, 2002). Sources of superoxide include the vascular tissues and polymorphonuclear leukocytes (Shurtz-Swirski et al., "Involvement of Peripheral Polymorphonuclear Leukocytes in Oxidative Stress and

Inflammation in Type 2 Diabetic Patients," Diabetes Care, Vol. 24:104-110, 2001). Superoxide Dismutase mimics have been shown to delay the onset of diabetes (AEOL10113 – Piganelli, et al., "A Metalloporphyrin-Based Superoxide Dismutase Mimic Inhibits Adoptive Transfer of Autoimmune Diabetes by a Diabetogenic T-cell Clone," Diabetes, Vol. 51:347-55, 2002.) in a cloned cell and prevented vascular and neural dysfunction in diabetic rats (M40403 – Coppey, et al., "Effect of M40403 Treatment of Diabetic Rats on Endoneurial Blood Flow, Motor Nerve Conduction Velocity and Vascular Function of Epineural Arterioles of the Siatic Nerve," British Journal of Pharmacology, Vol. 134:21-9, 2001). In patients with diabetic retinopathy serum level of lipid peroxides are higher than in healthy normals or patients with diabetes that do not have diabetic retinopathy. While levels of SOD remain the same in diabetics and normals, levels of ascorbic acid, a key anitoxidant, are lower in all diabetics (Gurler, et al., "The Role of Oxidative Stress in Diabetic Retinopathy" Eye, Vol. 14:73035, 2000) The results of these studies suggest that endogenous antioxidant mechanisms are overwhelmed in patients with diabetic retinopathy.

The use of intravenously dosed Mn SOD itself to treat or prevent oxidative stress-related tissue injury in humans, such as tissue damage due to cerebral or myocardial ischemia-reperfusion injury, has been unsuccessful due to bioavailability and immunogenic issues. These problems are thought to be due to the fact that Mn SOD is a high molecular weight species. A low molecular weight compound that catalyzes superoxide disproportionation with efficiency comparable to endogenous Mn SOD would be a good candidate for minimizing the aforementioned side effects. Salvemini et. al. have disclosed a class of Mn(II)-pentaaza macrocycle complexes as low molecular weight SOD mimics. For example, in a rat model of intestinal ischemia-reperfusion, 90% of animals dosed with 1 mg/kg of compound **4** survived after 4 h, compared to 0% survival for untreated animals [Salvemini, et. al., Science, Vol. 286:304, 1999; WO 98/58636; Salvemini, et al., Drugs Future, Vol. 25(10):1027, 2000], These compounds have also been disclosed for enhancing the stability of implanted biopolymeric prosthetic devices (including ocular implants; Ornberg et. al., WO 00/72893 A2) and for the treatment of pain (Salvemini et. al., U.S. Patent Nos. 6,180,620 B1 and 6,214,817B1).



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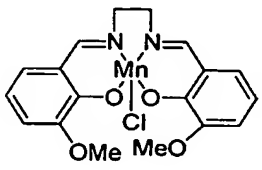
The use of certain Mn-salen complexes as SOD and catalase mimics with therapeutic activity has also been disclosed. For example, compound **5** has been shown to be neuroprotective in a rat stroke model (Baker *et. al.*, J. Pharmacol. Exp. Ther., Vol. 284:215-221, 1998; Doctrow *et. al.*, J. Med. Chem., Vol. 45:4549-4558, 2002), while compound **6** was found to increase the lifespan of mice that were deficient in endogenous expression of the enzyme superoxide dismutase 2 (Melov *et. al.*, J. Neurosci., Vol. 21:8348-8353, 2001).



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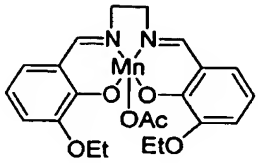

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Other investigators have reported the use of antioxidant compounds to treat ocular diseases. Crapo et. al., have disclosed the use of porphyrin-containing SOD mimics for treating glaucoma and macular degeneration (Crapo et. al., U.S. Patent Nos. 5,994,339 and 6,127,356). Campbell *et. al.* have disclosed the use of certain salen or bipyridyl Mn(II or III)phenolate complexes for treating uveitis and cataracts (Campbell et. al., U.S. Patent Nos. 6,046,188 and 6,177,419 B1). Levin has disclosed the use of carvedilol and its derivatives and metabolites as scavengers of ROS to reduce retinal ganglion cell death (WO 00/07584 A2). Brownlee has disclosed the use of a manganese tetrakis(benzoic acid) porphyrin for reducing ROS accumulation under high glucose conditions for treating diabetic retinopathy (Brownlee, WO 00/19993 A2). The stable free radical 4-hydroxy-2,2,6,6-tetramethylpiperidine-1-oxyl, a metal-free SOD mimic, has been reported to inhibited light-induced retinal damage in albino rats (Wang et. al., Res.

Commun. Mol. Pathol. Pharmacol., Vol. 89:291-305, 1995). However, in none of these reports were the compounds of the present invention disclosed or suggested for the treatment of AMD.

Summary of the Invention

This application is directed to the use of mimics of the enzyme, superoxide dismutase to treat persons suffering from the exudative and non-exudative forms of AMD, diabetic retinopathy, which includes preproliferative diabetic retinopathy (collectively DR) and retinal edema.

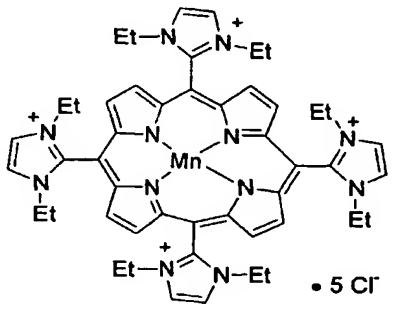
Detailed Description of the Invention

Posterior segment neovascularization is the vision-threatening pathology responsible for the two most common causes of acquired blindness in developed countries: exudative age-related macular degeneration (AMD) and proliferative diabetic retinopathy (PDR). Currently the only approved treatments for the posterior segment NV that occurs during exudative AMD are laser photocoagulation or photodynamic therapy with Visudyne®; both therapies involve occlusion of affected vasculature which results in localized laser-induced damage to the retina. Surgical interventions with vitrectomy and membrane removal are the only options currently available for patients with proliferative diabetic retinopathy. No strictly pharmacologic treatment has been approved for use against posterior segment NV, although several different compounds are being evaluated clinically, including, for example, anecortave acetate (Alcon, Inc.), EYE 001 (Eyetech), and rhuFabV2 (Genentech) for AMD and LY333531 (Lilly) and Fluocinolone (Bausch & Lomb) for diabetic macular edema.

In addition to changes in the retinal microvasculature induced by hyperglycemia in diabetic patients leading to macular edema, proliferation of neovascular membranes is also associated with vascular leakage and edema of the retina. Where edema involves the macula, visual acuity worsens. In diabetic retinopathy, macular edema is the major cause of vision loss. Like angiogenic disorders, laser photocoagulation is used to stabilize or resolve the edematous condition. While reducing further development of edema, laser photocoagulation is a cytodestructive procedure, that, unfortunately will alter the visual field of the affected eye.

An effective pharmacologic therapy for ocular NV and edema would likely provide substantial efficacy to the patient, in many diseases thereby avoiding invasive surgical or damaging laser procedures. Effective treatment of the NV and edema would improve the patient's quality of life and productivity within society. Also, societal costs associated with providing assistance and health care to the blind could be dramatically reduced.

It has now been discovered that certain SOD mimics are useful for the treatment of AMD, DR, and retinal edema. These compounds are of formulae **1** and **2**:



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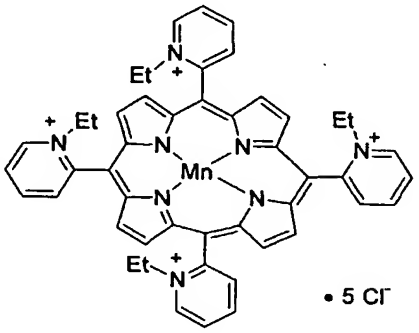

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Compounds **1** and **2** can be synthesized by methods disclosed in US Patent Number 6,127,356, the contents of which are hereby incorporated by reference.

Compounds **1** and **2** have been studied in several *in vivo* biological assays. For example Bowler *et. al.* have reported that in a rat stroke model, administration of **1** after induction of cerebral ischemia led to an attenuation of the increased expression of pro-inflammatory proteins, such as IL-6 and MIP-2 [Bowler *et. al.*, Free Radical Biology & Medicine, Vol. 33(8):1141-1152, 2002]. Also, Mackensen *et. al.* have disclosed that in rat stroke model, **2** reduces infarct volume when given to the rat either before or after induction of cerebral ischemia [Mackensen *et. al.*, Journal of Neuroscience, Vol. 21(13):4582-4592, 2001].

The present invention is also directed to the provision of compositions adapted for treatment of retinal and optic nerve head tissues. The ophthalmic

compositions of the present invention will include one or more SOD mimics and a pharmaceutically acceptable vehicle. Various types of vehicles may be used. The vehicles will generally be aqueous in nature. Aqueous solutions are generally preferred, based on ease of formulation, as well as a patient's ability to easily administer such compositions by means of instilling one to two drops of the solutions in the affected eyes. However, the SOD mimics of the present invention may also be readily incorporated into other types of compositions, such as suspensions, viscous or semi-viscous gels, or other types of solid or semi-solid compositions. Suspensions may be preferred for SOD mimics that are relatively insoluble in water. The ophthalmic compositions of the present invention may also include various other ingredients, such as buffers, preservatives, co-solvents, and viscosity building agents.

An appropriate buffer system (e.g., sodium phosphate, sodium acetate or sodium borate) may be added to prevent pH drift under storage conditions.

Ophthalmic products are typically packaged in multidose form. Preservatives are thus required to prevent microbial contamination during use. Suitable preservatives include: benzalkonium chloride, thimerosal, chlorobutanol, methyl paraben, propyl paraben, phenylethyl alcohol, edetate disodium, sorbic acid, polyquaternium-1, or other agents known to those skilled in the art. Such preservatives are typically employed at a level of from 0.001 to 1.0% weight/volume ("% w/v").

The route of administration (e.g., topical; ocular injection, parenteral, or oral) and the dosage regimen will be determined by skilled clinicians, based on factors such as the exact nature of the condition being treated, the severity of the condition, and the age and general physical condition of the patient.

In general, the doses used for the above described purposes will vary, but will be in an effective amount to prevent or treat AMD, DR, and retinal edema. As used herein, the term "pharmaceutically effective amount" refers to an amount of one or more SOD mimics which will effectively treat AMD, DR, and/or retinal edema in a human patient. The doses used for any of the above-described purposes will generally be from about 0.01 to about 100 milligrams per kilogram of body weight (mg/kg), administered one to four times per day. When the compositions are dosed topically, they will generally be in a concentration range of from 0.001 to about 5% w/v, with 1-2 drops

administered 1-4 times per day.

As used herein, the term "pharmaceutically acceptable carrier" refers to any formulation that is safe, and provides the appropriate delivery for the desired route of administration of an effective amount of at least one compound of the present invention.

The following Examples 1 and 2 are formulations useful for intraocular, periocular, or retrobulbar injection or perfusion.

EXAMPLE 1

Component	% w/v
Compound **1**	0.1
Dibasic sodium phosphate	0.2
HPMC	0.5
Polysorbate 80	0.05
Benzalkonium chloride	0.01
Sodium chloride	0.75
Edetate disodium	0.01
NaOH/HCl	q.s. to pH 7.4
Purified water	q.s. to 100%

EXAMPLE 2

Component	% w/v
Compound **2**	0.1
Cremophor EL	10
Tromethamine	0.12
Boric acid	0.3
Mannitol	4.6
Edetate disodium	0.1
Benzalkonium chloride	0.1
NaOH/HCl	q.s. to pH 7.4
Purified water	q.s. to 100%

EXAMPLE 3

The following tablet formulation can be made pursuant to U.S. Patent No. 5,049,586, incorporated herein by reference.

Component	% w/v
Compound **1**	60
Magnesium oxide	20
Corn starch	15
Polyvinylpyrrolidone	3
Sodium carboxymethylcellulose	1
Magnesium stearate	0.8

The invention has been described by reference to certain preferred embodiments; however, it should be understood that it may be embodied in

other specific forms or variations thereof without departing from its spirit or essential characteristics. The embodiments described above are therefore considered to be illustrative in all respects and not restrictive, the scope of the invention being indicated by the appended claims rather than by the foregoing description.